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FACTORS AFFECTING KNOWLEDGE SHARING IN BLOCKCHAIN TECHNOLOGY IN THE CHINESE CONSTRUCTION INDUSTRY

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Abstract. With the emergence of blockchain technology, knowledge sharing has become increasingly important for gaining a competitive advantage in any industry. However, it has not been fully implemented in the construction industry. This paper examines the factors influencing knowledge sharing in blockchain technology, using the Chinese construction industry as a case study. First, the study identified the key factors affecting knowledge sharing through a literature review and construction market research, classifying them based on the technology–organization–environment (TOE) framework. Next, the study employed focus group discussions to explore the relationships between pairs of factors and applied the interpretive structural modeling-matrix of cross-impact multiplication applied to classification (ISM-MICMAC) method to evaluate and prioritize these key factors. Finally, based on the empirical analysis, the paper discusses measures to promote knowledge sharing in the construction industry. This study contributes to the academic understanding of the factors influencing knowledge sharing and offers a fresh perspective for future research. Additionally, it provides practical insights to help the construction industry gain a competitive advantage and achieve sustainable development.

Keywords: blockchain technology, construction industry, influencing factor, ISM-MICMAC method, knowledge sharing, TOE theory.

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Notations

Variables and functions

A – S_j is influencing S_i;
B – the initial reachability matrix;
C – the finial reachability matrix;
C_{S_i,S_j} – the value at the corresponding position from factor S_i to factor S_j in the finial reachability matrix;
$D(S_i)$ – the driving power value of S_i;
$E(S_j)$ – the dependent power value of S_j;
I – the identity matrix;
M_{ij} – the structure self-intersection matrix;
O – S_i and S_j are influencing each other;
$Q(S_i)$ – the anecdote set;
$R(S_i)$ – the reachability set;
S_i/S_j – factor i/j, $i, j = 1, 2, ..., 9$;
V – S_i is influencing S_j;
X – S_i and S_j are unrelated.

Abbreviations

TOE – technology–organization–environment;
ISM-MICMAC – interpretive structural modeling-matrix of cross-impact multiplication applied to classification.

1. Introduction

The world is witnessing the rise of smart manufacturing across various industries, presenting both opportunities and challenges – particularly for the construction industry (Abu Adi et al., 2021). As a vital pillar of a nation's economy, the construction industry is undergoing a transformation towards knowledge – and technology – intensive, primarily reflected in the adoption of intelligent and digital technologies. However, its transformation is limited by technological, organizational, and environmental constraints (Fang et al., 2024). To overcome these challenges, knowledge management, especially knowledge sharing can help it gain a competitive advantage (Philsoophian et al., 2022). Knowledge sharing fosters innovation by injecting fresh ideas into the development of the construction industry (Lin, 2014). It involves the exchange of information, skills, and expertise among individuals, groups, or organizations, facilitating learning, collaboration, and innovation while enabling recipients to benefit from the knowledge and experience of others (Azeem et al., 2021). The construction industry accumulates considerable knowledge in the process of executing projects

(Zhang et al., 2016). However, due to the temporary nature and time constraints of projects, project teams are typically disbanded upon completion. As a result, knowledge related to construction technology, finance, and organizational management acquired during a project is often neither fully developed nor effectively transmitted within the organization (Yepes & López, 2021). Since team members often lack the time or the motivation to share knowledge accumulated from previous projects, leading to repeated mistakes and a lack of continuous improvements in the future construction projects (Ma et al., 2023). Therefore, effective knowledge sharing is essential for facilitating smart city development, engineering assessment. The study of its influencing factors is key to improving practical problems. Previous research has identified the factors influencing knowledge sharing in industries like education and business (Cormican et al., 2021). However, they can't address problems caused by the project-driven nature of the construction industry. Given the information-intensive and temporary nature of construction project, this study examines knowledge sharing in the context of blockchain technology, which is charaterized by security, decentralization, and transparency (Hsu et al., 2023), addressing a core requirement for secure knowledge sharing (Liang et al., 2023). Therefore, studying the key factors influencing knowledge sharing in the context of blockchain technology is valuable.

Studying influencing factors often requires categorizing them to better understand of their impacts on outcomes at different levels (Konstantinides et al., 2020). The technology–organization–environment (TOE) framework, widely used for such classification (Bakic-Miric, 2010), classifies factors into three dimensions: technological, organizational, and environmental (Gangwar et al., 2015). This study will integrate literature review, construction market research, and data from focus group discussions to study these factors. Additionally, analyzing the interrelationships between factors is crucial for selecting key factors. Common methods, such as Pearson's test, exploratory factor analysis, and structural equation modeling (Asparouhov et al., 2018; Malki et al., 2024), may result in weak correlations or multicollinearity when sample sizes are insufficient. The interpretive structural modeling (ISM) method can address these complex relationships, avoiding such issues and illustrating interactions between factors through a hierarchical structure (Shweta & Kumar, 2023). ISM utilizes experts' practical experience to decompose complex systems into subsystems and construct a multi-level structural model (Mathiyazhagan et al., 2013). However, ISM assumes equal relationship between factors, which may not reflect reality. The matrix of cross-impact multiplication applied to classification (MICMAC) method can further refine and prioritize key factors from ISM. It is a simple yet effective tool for determining the driving forces and dependencies of various elements (Mangla et al., 2018).

The aim of this research is to study the key factors influencing knowledge sharing in the construction industry within the context of blockchain technology. The three main research questions addressed in this paper are as follows: 1) How can the factors influencing knowledge sharing in the construction industry, in the context of blockchain technology, be fully identified? 2) How can the complex relationships between these factors be analyzed? 3) How can the construction industry improve its knowledge sharing practices? This study innovatively integrates the TOE framework with the ISM-MICMAC method to systematically identify, classify, and prioritize influencing factors, overcoming limitations of traditional statistical approaches. It also provides actionable strategies to enhance competitiveness and promote sustainable development in the Chinese construction industry. The remainder of the paper is organized as follows. Section 2 reviews the relevant literature and methods. Section 3 identifies, filters and classified the factors. Section 4 introduces research design. Section 5 presents the empirical analysis process and results. Section 6 discusses the findings and derives the implications. Final section concludes the paper and suggests directions for future research.

2. Literature review

With the increasingly fierce market competition, the construction industry must shift from labor-intensive models to knowledge-intensive approaches. Knowledge sharing has been recognized as an essential strategy for accelerating the digital transformation of the construction industry (Kale & Karaman, 2012). Moreover, knowledge sharing plays a crucial role in the development of various organizational capabilities, such as creativity and innovation, which are vital for enhancing organizational effectiveness (Alam et al., 2023). In recent years, scholars both domestically and internationally have analyzed the factors influencing knowledge sharing in various contexts, including supply-chain knowledge sharing, university research team knowledge sharing, internal company knowledge sharing, individual knowledge sharing, and virtual-community knowledge sharing (Wang & Liu, 2019). However, research on the factors influencing knowledge sharing in the construction industry is still in its early stages. Compared with more mature fields like healthcare or education, studies in this domain often lack a systematic understanding of the interdependencies among influencing factors, tending instead to examine them in isolation. This fragmented approach limits both theoretical development and practical implementation of effective knowledge-sharing strategies within project-based organizations. Given the diversity of subjects and the complexity of information involved in knowledge sharing within the construction industry, information leakage has become a significant barrier (Si & Zou, 2021). As a result, ensuring the security and stability of knowledge sharing has become a critical aspect of knowledge management (Huang et al., 2022). Blockchain technology provides a decentralized, tamper-proof distributed ledger, offering a promising solution to ensure secure and transparent data sharing without the need for intermediaries (Sanka et al., 2021). Rupa et al. (2021) found that blockchain played a pivotal role in secure supply-chain execution and identity verification through smart contracts. Implementing blockchain-based supply-chain systems enhances both effectiveness and security by ensuring transparency and traceability of products (Xu et al., 2024). Similarly, Beinke et al. (2019) proposed that blockchain could improve healthcare service quality by allowing different healthcare providers to securely share patients' electronic health records. Kuo et al. (2017) also explored the potential benefits of blockchain in improving data security, interoperability, transparency, and efficiency in healthcare systems. The application of blockchain technology is thus seen as a crucial measure to mitigate the risk of information leakage and protect the integrity of knowledge sharing. This study has selected blockchain technology as the technical framework for exploring the factors influencing knowledge sharing in the construction industry.

To study the factors influencing knowledge sharing in the construction industry within the context of blockchain technology, it is crucial to select appropriate analytical methods. Most existing studies rely on traditional statistical techniques – such as Pearson correlation tests, exploratory factor analysis, and structural equation modeling – which are effective for identifying direct correlations but insufficient for capturing the hierarchical and interdependent nature of influencing factors. Therefore, there remains a pressing need to adopt advanced methodologies capable of uncovering the complex relationships among these factors, especially in dynamic environments like the construction industry. The identification of key influencing factors must rely on a hierarchical classification of these factors. Matosková et al. (2022) employed Pearson's test to identify the statistical significance and connections between motivational factors affecting knowledge sharing. Akosile and Olatokun (2020) utilized an exploratory factor analysis model to examine the relationships between factors influencing knowledge sharing in higher education. Wang et al. (2023) applied structural equation modeling to analyze the factors affecting knowledge sharing in industrial technology innovation strategic alliances. However, these methods may not fully address issues like insufficient correlation and multicollinearity between variables. To better understand how these factors interact and influence one another, particularly in complex environments such as the construction industry, advanced methodologies capable of mapping causal hierarchies and identifying key leverage points are required. The ISM method has been widely used to analyze the complexity of relationships between factors (Yang et al., 2024). While ISM can determine the causal hierarchy among factors, it does not identify the key influencing factors in the system. MICMAC analysis, on the other hand, is useful for identifying the key targets for management and intervention in a system (Dubey et al., 2017). The combination of ISM and MICMAC (ISM-MICMAC) has been employed in previous research to examine the relationships between and strengths of influencing factors. For example, Liu et al. (2016) used ISM-MICMAC to analyze the relationships between critical success factors of China's construction projects, while Karmaker et al. (2023) applied ISM-MICMAC to identify and prioritize challenges related to Industry 5.0 implementation in emerging economies. Thus, this paper combines ISM and MICMAC to classify the levels of influencing factors in knowledge sharing. The TOE theory also helps simplify the factor analysis. This comprehensive theoretical framework, based on the context of technology applications, divides influencing factors into three categories: technology, organization, and environment (Chen et al., 2021). Technological factors include the characteristics of the technology itself and the organization's technological infrastructure. Organizational factors involve internal structures, cultures, and incentive systems that facilitate or hinder knowledge sharing. Environmental factors encompass external influences such as market conditions, regulatory policies, and competitive pressures (Cheng et al., 2024). Several scholars have applied the TOE framework to provide a multidimensional perspective for analyzing research results. For instance, Wang et al. (2016) concluded that the TOE theoretical framework offered a comprehensive internal and external analysis of the organizational adoption of innovative project models and was an effective theory for testing new technology adoption at the organizational level. Ullah et al. (2021) proposed a multilayered TOE-based risk-management framework for sustainable smart city governance. Therefore, this study adopts the TOE theory to guide the identification and classification of the key influencing factors in knowledge sharing, considering the technology, organization, and environment aspects. The goal is to improve knowledge-sharing performance in the Chinese construction industry by identifying the key factors influencing knowledge sharing in the context of blockchain technology.

3. Factor identification

3.1. Identification of influencing factors through literature review

To identify the factors influencing knowledge sharing in the construction industry in the context of blockchain technology, a literature review was conducted. The databases searched included Scopus, IEEE Xplore, and Web of Science, among others. The search keywords used included terms such as "factors influencing knowledge sharing", "blockchain technology", "the construction industry", "knowledge sharing opportunities and challenges", and "knowledge sharing benefits and limitations". As shown in Table 1, 21 influencing factors were identified.

Table 1. Identification of factors influencing knowledge sharing

Factor	Sources
Blockchain technology security	Philsoophian et al. (2022), Hsu et al. (2023)
Blockchain technology effectiveness	
Blockchain technology ease of use	
Customer loyalty	Akosile and Olatokun (2020)
Enterprise structure	Nguyen and Do (2021)
Enterprise culture	Razmerita et al. (2016)
Expected return	
Knowledge-sharing willingness	Zhang and He (2016)
Knowledge credibility	Ni et al. (2022), Le and Tuamsuk (2023), Wang et al. (2023)
Knowledge structure	
Knowledge diversity	
Knowledge usefulness	
Knowledge absorption	
Knowledge transformation	
National policy support	Ishdorj et al. (2024)
Self-efficacy	Wang and Liu (2019)
Sustainable R&D investment	Akosile and Olatokun (2020)
System norms	
Shared-platform stability	Vuori and Okkonen (2012)
Trust	Olan et al. (2022)
Team identification	

3.2. Filtering of influencing factors by experts

To ensure the validity of these factors, this study invited 10 experts to evaluate the 21 influencing factors identified through the literature review. To ensure the quality and relevance of expert input, participants were selected based on their specific experience in knowledge sharing and blockchain technology. Each expert met at least two of the following criteria: (1) research or practice in knowledge management, (2) involvement in blockchain-related projects, (3) publication in related fields, and (4) at least three years of relevant experience. Among them, 9 were technical and managerial personnel from the Chinese construction industry with practical experience in knowledge sharing and blockchain implementation and one was a university professor specializing in knowledge management and digital technologies in engineering education. Detailed background information on the respondents is provided in Table 2. The experts introduced in this section were not only involved in the factor screening process but also participated in the subsequent analysis, ensuring consistency and expertise throughout the study.

This study employed the Delphi method to gather expert opinions and reach a consensus. Two rounds of the Delphi process were conducted to refine and consolidate the factors based on the expert feedback. Additionally, a construction market survey was incorporated to validate these factors within the actual context of the construction industry, eliminating those deemed non-essential.

In the first Delphi round, the 10 experts analyzed the 21 factors listed in Table 1 and grouped those with similar characteristics. First, "trust", "team identification", "expected return", and "self-efficacy" were grouped into "knowledge-sharing willingness". Second, knowledge credibility, diversity, and usefulness were grouped as "knowledge structure". Third, factors related to blockchain technology were combined into "blockchain technology support". Finally, "shared-platform stability" and "enterprise culture" were consolidated into a comprehensive factor called "knowledge-sharing atmosphere".

In the second Delphi round, the experts, in combination with insights from the construction market survey, refined the factors. They concluded that "strict system norms cannot accommodate the flexibility required for knowledge sharing in the construction industry … customer loyalty primarily influences customer retention and business relationships, rather than internal or inter-organizational knowledge exchange". Additionally, they noted that "enterprise structure" refers to the series of initiatives an enterprise implements to promote knowledge sharing. It overlaps with the incentive system and R&D investment, and was therefore removed. As a result, the factors "system norms", "customer loyalty", and "enterprise structure" were eliminated because they were either irrelevant or unnecessary for knowledge sharing within the construction industry.

In conclusion, 9 final influencing factors were identified for further discussion and are provided in Table 3. Blockchain technology support is a key element in improving data interoperability in facility management, enhancing the precision of point cloud data for as-built models of existing facilities (Adel et al., 2023). It also provides a foundation of trust for knowledge sharing in the construction industry by enabling effective management of intellectual property rights and offering an immutable record of knowledge transactions. Knowledge-sharing willingness is closely re-

Table 2. Background information on respondents

Respondent	University professor	Technical and managerial staff from Chinese construction industry			
		Technical director	Project manager	Human resource manager	Commercial manager
Number	1	3	3	2	1
Years of experience in knowledge management	5	5–7	4–6	4–5	3
Involvement in blockchain-related projects (Yes/No)	Yes	Yes	Yes	Yes	Yes
Number of papers published in related fields	3	2	2	0	1

lated to trust, which evaluates the scientific truthfulness of knowledge (Jin et al., 2021). This willingness serves as a crucial driving force that influences the breadth, depth, and efficiency of knowledge sharing. Knowledge structure plays a pivotal role in knowledge absorption and transformation (Li et al., 2016), affecting content screening, dissemination paths, and collaborative outcomes. Knowledge absorption and transformation are essential for knowledge sharing, enhancing innovation capacity and operational efficiency (Zhuo & Chen, 2023). Incentive system sustainability provides lasting motivation for knowledge sharing within enterprises, driving their continuous development. It is critical for an organization's forward planning in technology and knowledge sharing (Kuo et al., 2017). Sustainable R&D investment promotes knowledge sharing and innovation through purchasing equipment, organizing seminars, and building platforms. A knowledge-sharing atmosphere fosters the exchange of experience and technology within enterprises, stimulates innovation, and enhances overall competitiveness. National policy support offers enterprises funding, guidance, and resource assurance, powerfully promoting knowledge sharing and industry advancement. The 9 factors influencing knowledge sharing – spanning technological empowerment, organizational dynamics, policy support, and trust mechanisms – collectively foster an innovation ecosystem in the construction industry through blockchain integration, optimized knowledge governance, sustainable incentives, and collaborative innovation.

3.3. Determination of influencing factors based on TOE theory

Based on the TOE theory, the influencing factors were classified to facilitate analysis under different categories. The technological dimension ensures that blockchain technology supports the integrity of knowledge, making it immutable and verifiable, which builds trust among participants. In the organizational dimension, knowledge-sharing willingness reflects employees' readiness and motivation to share their expertise, while a good knowledge structure supports better decision-making and innovation. Knowledge absorption refers to an organization's ability to absorb, understand, and apply new knowledge, while knowledge transformation involves converting tacit knowledge into explicit knowledge, enabling more effective use and dissemination. Incentive system sustainability ensures that long-term rewards are in place for knowledge sharing, motivating employees to contribute regularly. Sustainable R&D investment promotes ongoing innovation and the continuous improvement of knowledge-management practices, allowing the organization to remain competitive and adaptable in a rapidly changing environment. The environmental dimension is divided into the enterprise and national levels. A knowledge-sharing atmosphere shapes the organizational environment to foster knowledge exchange, and national policy support influences the external regulatory environment and government support for knowledge sharing. In summary, the technological dimension, with blockchain, ensures knowledge integrity; the organizational dimension covers internal elements; and the environmental dimension, split into enterprise and national levels, shapes the external context. Table 3 presents the final classification of the influencing factors.

4. Research design

4.1. Development of structural self-intersection matrix

A structural self-intersection matrix reflects the relationships among the influencing factors (Naheed et al., 2024). However, determining the relationships between factors

Table 3. Dimensions of the factors

Factor	Description	Dimension
Blockchain technology support (S1)	This provides a centralized repository for knowledge assets, making knowledge easier to capture, store, and retrieve.	Technological dimension
Knowledge-sharing willingness (S2)	This is the subjective intention of an individual to share knowledge with others.	Organizational dimension
Knowledge structure (S3)	This cognitive framework represents the organization and interrelationships of concepts, facts, and procedures in a particular domain.	
Knowledge absorption (S4)	This is the ability of an individual or organization to acquire, understand, and integrate new information.	Organizational dimension
Knowledge transformation (S5)	This is the ability to add value to knowledge or make it more suitable for a particular purpose.	
Incentive system sustainability (S6)	An incentive program can maintain an incentive effect on employees in the long term.	
Sustainable R&D investment (S7)	This is long-term, stable, and environmentally friendly investment in R&D activities.	
Knowledge-sharing atmosphere (S8)	This prioritizes trust and encourages employees to share their knowledge without fear of negative repercussions.	Environmental dimension (enterprise level)
National policy support (S9)	This plays a crucial role in facilitating knowledge sharing by providing a conducive regulatory and incentive framework.	Environmental dimension (national level)

depends on the subjective judgement of experts, which may lead to disagreement. To address this, the study employed focus group discussions. During these discussions, experts were asked about the contextual relationship between any two factors (S_i and S_j). In cases of disagreement, the experts reached a consensus after lengthy discussion.

The relationships between the factors were represented using the following matrix format:

$$M_{ij} = \begin{cases} V & S_i \text{ is influencing } S_j \\ A & S_j \text{ is influencing } S_i \\ O & S_i \text{ and } S_j \text{ are influencing each other} \\ X & S_i \text{ and } S_j \text{ are unrelated} \end{cases} \quad (i = 1, 2, \ldots, 9), \tag{1}$$

where M_{ij} denotes the structural self-intersection matrix and V, A, O, and X represent different types of influencing relationships between factors S_i and S_j.

4.2. Construction and calculation of reachability matrix

A reachability matrix is divided into the initial reachability matrix and the final reachability matrix, and its construction and calculation follow specific rules and processes.

The initial reachability matrix is a binary matrix derived from the structural self-intersection matrix. Table 4 presents the substitution rule used in this study. Specifically, when the correlation direction between two factors was represented by the symbols V, A, X, or O, the (S_i, S_j) and (S_j, S_i) positions in the reachability matrix were filled with the corresponding values from Table 4. For example, if the relationship between S1 and S2 in the structural self-intersection matrix was labeled V, then (S1, S2) in the initial reachability matrix would be filled with 1 and (S2, S1) would be filled with 0. In this study, the initial reachability matrix is denoted B.

Table 4. Substitution rule

Structural self-intersection matrix	Initial reachability matrix	
(S_i, S_j)	(S_i, S_j)	(S_j, S_i)
V	1	0
A	0	1
X	0	0
O	1	1

The final reachability matrix was obtained from the initial reachability matrix by checking and incorporating transitivity. Transitivity is a fundamental assumption in the ISM model which posits that if S_i is related to S_j and S_j is related to S_k, then S_i must necessarily be related to S_k. To capture indirect relationships between factors, an identity matrix must be introduced for further processing of the initial reachability matrix. The final reachability matrix is then derived using Boolean matrix operations, as described in Eqn (2):

$$C = \left(B + I\right)^n,$$
$$\text{when } \left(B+I\right) \neq \left(B+I\right)^2 \neq \ldots \neq \left(B+I\right)^{n-1} \neq$$
$$\left(B+I\right)^n \text{ and} \left(B+I\right)^n = \left(B+I\right)^{n+1}. \tag{2}$$

Equation (2) defines the relationship between the final reachability matrix C, the initial reachability matrix B, and the identity matrix I. The equation shows that the matrix operations are performed iteratively until the results stabilize, indicating the inclusion of indirect relationships between factors. This process ensures that indirect relationships are accurately captured and that the final reachability matrix reflects both direct and indirect influences between the factors.

4.3. Determination of level partition and ISM model

This step aids in classifying the relationships among complex factors and constructing a structural model. During this process, certain key datasets need to be defined. The reachability set refers to the set of all row vector elements that can be reached by element S_i in the final reachability matrix, while the antecedent set represents all column vector elements that can reach S_i in the final reachability matrix.

Equation (3) defines the relationship between the reachability set $R(S_i)$ and the antecedent set $Q(S_i)$ as follows:

$$R\left(S_i\right) \cap Q\left(S_i\right) = R\left(S_i\right) \left(i = 1, 2, \ldots, 9\right). \tag{3}$$

In Eqn (3), $R(S_i)$ denotes the reachability set of factor S_i and $Q(S_i)$ denotes the antecedent set of factor S_i. Elements with the same reachability and intersection sets are placed at the top level of the ISM hierarchy. The top-level elements are those that are either influenced by or drive other elements. Once the top-level element is identified, it is removed from the element set. The process is then repeated to identify the elements for the next level. This iteration continues until the levels of all variables are determined. The identified levels are then used to construct the final model of the digraph and ISM.

The establishment of the ISM model typically involves inputting the relevant matrix data into software tools for analysis. If there is a relationship between factors S_i and S_j, it is represented by an arrow pointing from S_i to S_j. SPSS, a tool used for statistical analysis and data processing, is also commonly applied for ISM modeling (Ullah et al., 2024). Therefore, this study used SPSS to develop the ISM model.

4.4. Drawing of four-quadrant diagram based on MICMAC model

A four-quadrant diagram illustrates the interactions between factors and their degrees of influence. It is constructed by determining the quadrants based on the driving forces and the dependent forces. The driving power value $D(S_i)$ of a factor is calculated as the sum of the values in the corresponding row of the final reachability matrix, while the dependent power value $E(S_j)$ is determined by summing the values in the corresponding column of the matrix. Based on these calculations, a coordination graph is plotted, showing the relationship between driving power and dependence for each influencing factor. This diagram helps to visualize the relative impact and influence of each factor within the system.

$$D(S_i) = \sum_{j=1}^{n} C_{S_i,S_j} \left(j = 1, 2, \ldots, 9 \right); \quad (4)$$

$$E(S_j) = \sum_{i=1}^{n} C_{S_i,S_j} \left(i = 1, 2, \ldots, 9 \right). \quad (5)$$

In Eqns (4) and (5), C_{S_i,S_j} denotes the value at the corresponding position from factor S_i to factor S_j in the finial reachability matrix; $D(S_i)$ denotes the driving power value of factor S_i; and $E(S_j)$ demotes the dependent power value of factor S_j. These values are used to calculate the driving and dependent powers of each factor, which are essential for analyzing the interactions and influence levels within the system.

Based on their driving power and dependent power, influencing factors can be classified into four categories. Factors with low driving power and low dependence are termed autonomous factors (Quadrant I), as they have minimal impact on the system. Factors with high dependence and low driving power are called dependent factors (Quadrant II), as they are highly influenced by other factors but exert little influence themselves. Factors with both high driving power and high dependence are known as linkage factors (Quadrant III), as they significantly influence the system while also being strongly influenced by other factors. Finally, factors with low dependence and high driving power are referred to as driving factors (Quadrant IV), as they have significant impact on the system but are not heavily influenced by other factors. This classification can aid the construction industry in understanding the importance and interrelationships of various factors, providing a foundation for strategic decision-making.

5. Empirical analysis

5.1. Development of structural self-intersection matrix

Ten experts with engineering management experience, including university professors and workers from the Chinese construction industry, were invited to discuss and determine the relationships among the factors listed in Table 3. These experts were the same individuals who filtered the factors influencing knowledge sharing within the construction industry in the context of blockchain technology. All participants were familiar with the symbols *V*, *A*, *O*, *X*, as well as the purpose of the study. They collaborated to discuss the interactions between the various factors and, in cases where opinions differed, they engaged in discussion until they reached a consensus.

During the discussions, the majority of experts agreed that national policy support (S9) is the most important factor influencing technological, organizational, and environmental incentives for knowledge sharing in the construction industry. Regarding knowledge structure, it was considered a characteristic element that plays direct roles in knowledge absorption (S4) and knowledge transformation (S5).

One expert commented: "National policies play a significant role in guiding the formulation of enterprise development strategies. They promote technology adoption, enhance a culture of sharing, optimize knowledge management, and improve the innovation environment, systematically driving the development of all related factors". Another expert added: "A robust knowledge structure can streamline the application of knowledge in practical situations". The experts also highlighted the necessity of ensuring stable knowledge-sharing platforms based on technological support: "Blockchain technology support enhances knowledge sharing in the construction industry by providing a secure, transparent, and immutable platform for data exchange and collaboration…".

The contextual relationships between each factor were captured in the spatial reachability matrix, which was then output as the structural self-intersection matrix. For instance, the first row of the matrix indicates that blockchain technology support (S1) influences knowledge-sharing willingness (S2), but S2 does not influence S1, so a *V* was assigned to the corresponding position according to Eqn (1). Similarly, national policy support (S9) influences S1, but S1 does not affect S9, so *A* was used to describe this relationship. The relationships of *O* and *X* are similarly filled in their respective places. The resultant structural self-intersection matrix is shown in Table 5.

Table 5. Structural self-intersection matrix

Factor	S9	S8	S7	S6	S5	S4	S3	S2
S1	*A*	*O*	*A*	*X*	*V*	*V*	*X*	*V*
S2	*A*	*A*	*A*	*A*	*A*	*A*	*X*	–
S3	*X*	*X*	*X*	*X*	*V*	*V*	–	–
S4	*A*	*A*	*A*	*A*	*O*	–	–	–
S5	*A*	*A*	*A*	*A*	–	–	–	–
S6	*A*	*A*	*O*	–	–	–	–	–
S7	*A*	*X*	–	–	–	–	–	–
S8	*A*	–	–	–	–	–	–	–
S9	–	–	–	–	–	–	–	–

According to Table 5, the structural self-intersection matrix highlights the complex and interdependent nature of the factors influencing knowledge sharing within the Chinese construction industry. S1 acts as an originator for S2, S4, and S5, indicating that blockchain technology support (S1) significantly influences the efficiency of knowledge sharing. Additionally, national policy support (S9) influences most of the other factors, making it key points of focus for optimizing knowledge-sharing practices.

5.2. Construction and calculation of reachability matrix

The initial reachability matrix was primarily used to convert the relationships between the factors in the structural self-intersection matrix into binary values, which simplified subsequent matrix calculations. It identified the direct interactions (originator–recipient relationships) between the factors. Each cell in the matrix was assigned 1 if there was a direct interaction from the row factor to the column factor and 0 if there was no direct interaction (Table 4). For example, Table 5 shows that S9 influences S1, so in the initial reachability matrix S19 = 0 and S91 = 1. The same process was applied to the other elements and the initial reachability matrix is presented in Table 6.

Table 6. Initial reachability matrix

Factor	S1	S2	S3	S4	S5	S6	S7	S8	S9
S1	1	1	0	1	1	0	0	1	0
S2	0	1	0	0	0	0	0	0	0
S3	0	0	1	1	1	0	0	0	0
S4	0	1	0	1	1	0	0	0	0
S5	0	1	0	1	1	0	0	0	0
S6	0	1	0	1	1	1	1	0	0
S7	1	1	0	1	1	1	1	0	0
S8	1	1	0	1	1	1	0	1	0
S9	1	1	0	1	1	1	1	1	1

To obtain the final reachability matrix, the transitivity of the initial reachability matrix was examined. In the final reachability matrix, an asterisk (1*) indicates an indirect influencing relationship between factors, taking transitivity into account. According to Eqn (2), the indirect relationships were identified and the final reachability matrix is presented in Table 7. As shown in Table 7, incentive system sustainability (S6) has an interactive relationship with the sustainable R&D investment (S7), but it does not have a direct influence on blockchain technology support (S1). However, an enterprise's incentive system sustainability impacts the effectiveness of R&D investment for knowledge sharing. Therefore, S6 has an indirect influence on S1, as demonstrated by the 1* in the matrix.

Table 7. Final reachability matrix

Factor	S1	S2	S3	S4	S5	S6	S7	S8	S9
S1	1	1	0	1	1	0	0	1	0
S2	0	1	0	0	0	0	0	0	0
S3	0	1*	1	1	1	0	0	0	0
S4	0	1	0	1	1	0	0	0	0
S5	0	1	0	1	1	0	0	0	0
S6	1*	1	0	1	1	1	1	0	0
S7	1	1	0	1	1	1	1	0	0
S8	1	1	0	1	1	1	1*	1	0
S9	1	1	0	1	1	1	1	1	1

The asterisk symbol * indicates an indirect influencing relationship between factors. As shown in Table 7, factors S3, S6, and S8 exhibit indirect influencing relationships with several other factors. By considering both direct and indirect influences, it becomes clear that S1, S3, S6, S7, S8, and S9 play crucial roles in enhancing knowledge-sharing efficiency. Therefore, the construction industry should prioritize managing and coordinating these factors to maximize their impact on the knowledge-sharing process.

5.3. Determination of level partition and ISM model

Step 1: Determine the $R(S_i)$ of each factor. $R(S_i)$ refers to the set of factors that are subject to factor S_i. As shown in Table 7, for instance, S1 influences S2, S4, S5, and S8, so $R(S1)$ is {S1, S2, S4, S5, S8}. The corresponding $R(S_i)$ for the remaining factors can be obtained using the same process. The results are displayed in Table 8.

Step 2: Determine the $Q(S_i)$ of each factor. $Q(S_i)$ represents the set of factors that influence factor S_i. As indicated in Table 7, S1 is influenced by S6, S7, S8, and S9, so $Q(S1)$ is {S1, S6, S7, S8, S9}. The corresponding $Q(S_i)$ for the other factors can be determined similarly. The results are shown in Table 8.

Step 3: Calculate $R(S_i) \cap Q(S_i)$. After determining $R(S_i)$ and $Q(S_i)$, calculate $R(S_i) \cap Q(S_i)$. This represents the factors that are both subject to and influence factor S_i. The results of these calculations are presented in Table 8.

Table 8. The results of iteration I

Factor	$R(S_i)$	$Q(S_i)$	$R(S_i) \cap Q(S_i)$
S1	S1, S2, S4, S5, S8	S1, S6, S7, S8, S9	S1, S8
S2	S2	S1, S2, S3, S4, S5, S6, S7, S8, S9	S2
S3	S2, S3, S4, S5	S3	S3
S4	S2, S4, S5	S1, S3, S4, S5, S6, S7, S8, S9	S4, S5
S5	S2, S4, S5	S1, S3, S4, S5, S6, S7, S8, S9	S4, S5
S6	S1, S2, S4, S5, S6, S7	S6, S7, S8, S9	S6, S7
S7	S1, S2, S4, S5, S6, S7	S6, S7, S8, S9	S6, S7
S8	S1, S2, S4, S5, S6, S7, S8	S1, S8, S9	S1, S8
S9	S1, S2, S4, S5, S6, S7, S8, S9	S9	S9

Step 4: Iterate to obtain the factor hierarchy. According to Eqn (3), S2 is the only factor for which $R(S2) \cap Q(S2) = R(S2)$, meaning S2 is extracted as Level I. This marks the completion of Iteration I. Following this step, the process continues through subsequent iterations. After four iterations, the factors are classified into Levels I to V. The detailed iteration process is presented in Table 9. This hierar-

Table 9. Level partitions for factors: iterations I–IV

Factor	$R(S_i)$	$Q(S_i)$	$R(S_i) \cap Q(S_i)$	Level
S1	S1, S8	S1, S8, S9	S1	IV
S2	S2	S1, S2, S3, S4, S5, S6, S7, S8, S9	S2	I
S3	S3	S1, S3, S6, S7, S8, S9	S3	III
S4	S4, S5	S1, S3, S4, S5, S6, S7, S8, S9	S4	II
S5	S4, S5	S1, S3, S4, S5, S6, S7, S8, S9	S5	II
S6	S1, S6	S1, S3, S6, S7, S8, S9	S6	III
S7	S1, S7	S1, S3, S6, S7, S8, S9	S7	III
S8	S1, S8	S1, S8, S9	S8	IV
S9	S9	S9	S9	V

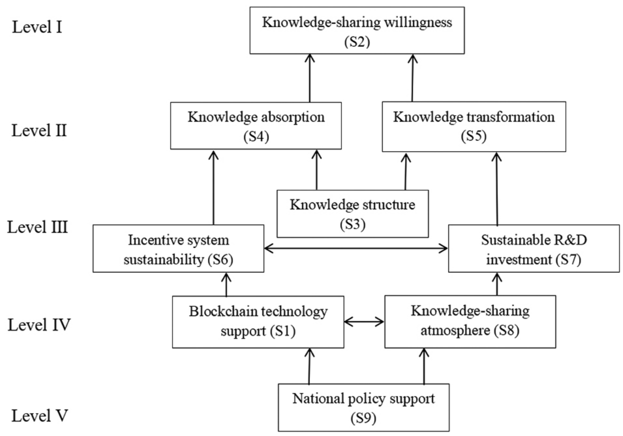

Figure 1. Hierarchy diagram

chical classification provides a clearer understanding of the relative importance and influence of each factor in knowledge sharing within the context of blockchain technology.

The hierarchical classification presented in Table 9 highlights the relative importance of each factor within the context of blockchain-supported knowledge sharing. Through an iterative process, the factors were divided into five distinct levels (I to V), revealing the depth of influence and interdependence among them. S2 was identified as the most foundational factor (Level I), while S4 and S5, which are influenced by S2, in turn influence multiple other factors (Level II). S3, S6, and S7 exhibit a higher degree of interdependence (Level III). S1 and S8, although influencing fewer other elements, show a high level of dependency on the other factors (Level IV). Lastly, S9 is the least dependent, standing alone at Level V. This classification provides insights into the critical roles and interrelationships of each factor in the knowledge-sharing process.

To develop the ISM model, SPSS 28.0 software was used by inputting the correlations between each factor, as shown in Figure 1. The relationships between factors *Si* and *Sj* are represented by arrows pointing from S_i to S_j. As indicated in Table 9, knowledge-sharing willingness (S2), located at Level I, is positioned at the top of the ISM model.

Figure 1 illustrates the hierarchy of the factors influencing knowledge sharing in the construction industry. The factors are distributed across five levels, each representing an increasing degree of influence and complexity. At the topmost level (Level I), knowledge-sharing willingness (S2) indicates a psychological disposition for knowledge sharing. Level II consists of knowledge absorption (S4) and knowledge transformation (S5), both of which are essential for converting and assimilating information effectively. Level III includes three factors: incentive system sustainability (S6), knowledge structure (S3), and sustainable R&D investment (S7). These factors act as mediators between the top and bottom levels, ensuring that knowledge sharing is supported by appropriate structures and investments. Level IV contains blockchain technology support (S1) and knowledge-sharing atmosphere (S8). Blockchain technology plays a critical role in facilitating secure and efficient knowledge exchange, while a supportive knowledge-sharing atmosphere encourages employees to engage in knowledge-sharing activities. Finally, at Level V, national policy support (S9) is positioned at the base of the hierarchy, serving as the underlying support for the entire knowledge-sharing ecosystem. National policies help create a conducive environment for knowledge sharing by promoting favorable regulations and incentives.

5.4. Drawing of four-quadrant diagram based on MICMAC method

According to Eqns (4) and (5), the driving power $D(S_i)$ and dependent power $E(S_i)$ of each factor were calculated. The results are presented in Table 10.

Table 10. D_i and E_j for each factor

Factor	$D(S_i)$	$E(S_i)$
S1	5	5
S2	1	9
S3	4	1
S4	3	8
S5	3	8
S6	6	4
S7	6	4
S8	7	3
S9	8	1

The four-quadrant diagram was created by evaluating the driving force and the dependent force of each factor. The dependent force is represented on the horizontal axis, while the driving force is on the vertical axis. For instance, D(S2) = 1 and E(S2) = 9 indicates that S2 influences or drives one barrier but is influenced by 9 barriers. As a result, S2 is positioned in Quadrant II. Figure 2 illustrates the positions of the 9 factors according to their driving power and dependent power.

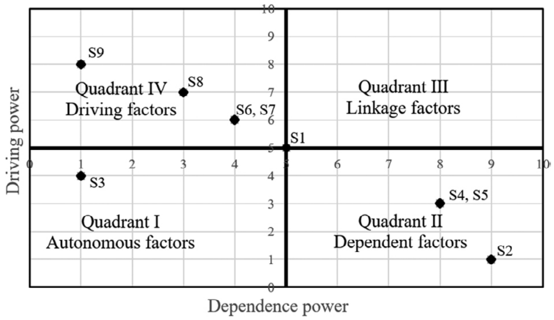

Figure 2. Four-quadrant diagram

It can be observed from Figure 2 that there is no factor in Quadrant III. S3 is the autonomous factor positioned in Quadrant I, operates independently, requiring minimal external intervention while delivering high-impact motivation for knowledge sharing. Additionally, S2, S4, and S5 are placed in Quadrant II, suggesting that they are strongly influenced by other factors but have relatively weak driving power. These factors may require additional support or intervention to enhance their effectiveness in promoting knowledge sharing. On the other hand, this study found that S6, S7, S8, and S9 are located in Quadrant IV, indicating that they are highly influential. These factors play critical roles in the knowledge-sharing ecosystem and should be prioritized when developing strategies to optimize the process. A noteworthy finding is the special positioning of S1, which is located at the central origin of the four-quadrant diagram. This unique placement sets it apart from the traditional categorizations within the MICMAC matrix. The study highlights the distinctive role of blockchain technology support in facilitating knowledge sharing. This positioning reflects that blockchain technology is not merely influenced by or influencing other factors in the traditional sense (Attri et al., 2020; Hsu et al., 2023). Instead, it acts as a driver of change on its own. Its primary function is to establish a trustworthy foundation for knowledge sharing, independent of the influences of other factors. This special positioning underscores the importance of technological infrastructure and commitment to innovation in promoting effective knowledge sharing within organizations. Organizations that adopt blockchain technology can benefit from increased transparency, reduced transaction costs, and improved collaboration, all of which are essential for successful knowledge-sharing initiatives. Therefore, the Chinese construction industry should place greater emphasis on investing in blockchain technology to enhance its knowledge-sharing performance.

6. Discussion

According to the results of the empirical analysis, this paper identifies S1, S6, S7, S8, and S9 as the key factors influencing knowledge sharing. These findings align with previous research conclusions that emphasize the importance of technological infrastructure, organizational culture, and environment atmosphere in facilitating effective knowledge sharing (Kiomjian et al., 2020; Le & Tuamsuk, 2023). Based on the TOE theory, these key factors can be categorized into technological, organizational, and environmental dimensions. In the technological dimension, Qiao et al. (2021) found that blockchain technology provides an immutable ledger for documenting project experience and lessons learned, enhancing transparency and traceability across project. Similarly, Xie and Zhang (2023) demonstrated how blockchain-based platforms can improve stakeholder coordination and reduce information asymmetry, thereby supporting more effective transfer. In this study, blockchain technology support (S1) not only enables the capture and storage of both tacit and explicit knowledge, but also facilitates its retrieval through decentralized access mechanisms. This aligns with prior research indicating that blockchain technology can significantly enhance knowledge sharing in the construction industry, leading to greater innovation, improved efficiency, and sustainable competitive advantage. In organizational dimension, incentive system sustainability (S6) and sustainable R&D investment (S7) emerged as significant motivation. Ni et al. (2022) highlighted that without proper motivation, employees may be reluctant to share their expertise due to concerns about personal loss or lack of recognition. Our finding reinforces this by showing that a well-designed incentive system enhances individuals' willingness to contribute to collective knowledge. Furthermore, Li (2020) emphasized that continuous R&D investment fosters innovation and enriches the pool of knowledge available for sharing. In this study, S7 was found to significantly impact the depth and breadth of knowledge exchange, particularly in fast-evolving construction environments where new materials, methods, and tools are frequently introduced. In the environmental dimension, knowledge-sharing atmosphere (S8) and national policy support (S9) were identified as key enablers. Zhang and He (2016) noted that a culture of openness and trust within organizations strongly influences employees' readiness to share knowledge. This is especially relevant in the Chinese construction industry, where hierarchical structures often inhibit open communication. The current study confirms that fostering such an environment encourages informal knowledge exchanges, peer learning, and cross-functional collaboration. Additionally, Wanberg et al. (2017) pointed out that government policies, such as subsidies for digital transformation or mandates for data transparency, can create institutional pressures that promote knowledge-sharing behaviors. Our findings suggest that S9 acts as an external catalyst, providing regulatory clarity and financial incentives that reduce the risks associated with adopting new technologies like blockchain.

Although several studies have examined knowledge sharing in the construction industry, few have specifically explored it in the context of blockchain technology. For instance, Qin et al. (2020) applied the TOE framework to investigate ERP adoption in manufacturing but did not consider knowledge management practices. In contrast, this study extends the TOE model by incorporating blockchain-specific features, such as decentralization and immutability, to analyze their impact on knowledge-sharing dynamics. Moreover, unlike traditional statistical approaches used in earlier works (Adegoriola et al., 2023), this research adopts the ISM-MICMAC method to reveal hierarchical relationships among factors, offering a more nuanced understanding of their interdependencies. Another key difference lies in the focus on sustainability. While many studies emphasize short-term performance improvements (Cormican et al., 2021), this paper highlights the need for long-term strategies, such as sustainable incentive systems and R&D investments, to ensure continuous knowledge creation and dissemination. This aligns with recent trends in smart city development and green construction, where knowledge reuse and innovation play central roles in achieving environmental and social sustainability (Mathivathanan et al., 2021).

Based on the TOE framework, this study proposes a comprehensive set of practical and effective strategies across technological, organizational, and environmental dimensions to enhance the efficiency and sustainability of knowledge sharing within the construction industry, particularly under the context of blockchain technology. From a technological perspective, the development of a blockchain-based knowledge-sharing platform is proposed as a foundational solution to overcome traditional barriers such as information leakage, data insecurity, and inefficient dissemination. This platform would function as a decentralized repository capable of securely storing and managing both explicit knowledge (e.g., project reports, technical specifications) and tacit knowledge (e.g., expertise, best practices). To facilitate the conversion of tacit into explicit knowledge, commonly referred to as externalization, the system should integrate interactive tools such as collaborative workspaces, real-time discussion forums, and smart contract-enabled access controls. These features not only support seamless knowledge exchange but also ensure data integrity and traceability, addressing critical concerns related to intellectual property and confidentiality. At the organizational level, it is essential to cultivate a culture that values and encourages knowledge contribution and reuse. Toward this end, implementing a sustainable incentive system is recommended to motivate employees through structured reward mechanisms, including performance-based recognition, career advancement opportunities, and peer-to-peer acknowledgment systems. Such incentives can significantly enhance individuals' willingness to share knowledge, especially in hierarchical or risk-averse environments commonly found in construction firms. Furthermore, maintaining consistent R&D investments will support the continuous development and adaptation of new digital tools, enriching the knowledge pool and fostering innovation. These investments are crucial for ensuring long-term competitiveness and adaptability in an increasingly dynamic and technology-driven industry landscape. From an environmental standpoint, creating a supportive ecosystem that promotes trust, collaboration, and transparency among stakeholders is vital for sustaining knowledge-sharing behaviors. This includes encouraging cross-functional teamwork, inter-organizational cooperation, and open communication channels throughout the project lifecycle. Additionally, aligning internal initiatives with favorable national policies and regulatory frameworks, such as those promoting digital infrastructure, green construction, and smart city development, can provide institutional backing for knowledge-sharing practices. Governmental support in the form of subsidies, tax incentives, and standardization efforts can further catalyze the adoption of blockchain-based solutions and foster a broader culture of innovation and knowledge diffusion across the industry. By integrating these multi-dimensional strategies, this study contributes not only to the theoretical development of knowledge management in project-based industries but also offers practical guidance for policymakers, industry leaders, and technology developers aiming to harness the transformative potential of blockchain in the construction industry.

7. Conclusions

This study has successfully investigated the key factors influencing knowledge sharing in blockchain technology, using the Chinese construction industry as a case study. Through a literature review and expert opinion filtering, 9 key factors affecting knowledge sharing in the construction industry within the context of blockchain technology have been identified. These factors are: blockchain technology support, knowledge-sharing willingness, knowledge structure, knowledge absorption, knowledge transformation, incentive system sustainability, sustainable R&D investment, knowledge-sharing atmosphere, and national policy support.

The ISM-MICMAC analysis has highlighted blockchain technology support, a sustainable incentive system, sustainable R&D investment, a supportive knowledge-sharing atmosphere, and favorable national policy support as the primary factors influencing knowledge sharing in the construction industry. These factors align with the TOE theory, covering technological, organizational, and environmental dimensions. Notably, blockchain technology support occupies a distinct position in the MICMAC matrix, emphasizing its crucial role in establishing a reliable foundation for knowledge sharing. This underscores the importance of technological infrastructure and innovation in fostering effective knowledge sharing.

Based on the analysis, strategies have been proposed to enhance knowledge-sharing performance in the construction industry across technological, organizational, and environmental dimensions. This study supports the construction industry by simplifying knowledge-sharing activities, improving information accessibility, and strengthening learning and development initiatives. Furthermore, it contributes to global academic research by expanding the understanding of the factors influencing knowledge sharing. However, the study acknowledges limitations in the case study's scope and in its exploration of tacit and explicit knowledge. Future research could address these limitations by expanding the case study and further examining the transformation between tacit and explicit knowledge in the construction industry.

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